

From studies of ALH84001,53, we suggested that silica, plagioclase and carbonate were shock melted and partly dispersed into fractured pyroxene [1,2] during a 4 Ga impact [3]. This conclusion severely weakens arguments of McKay et al. [4] for relic biogenic activity in carbonates. Here we report studies of a second section and other arguments for shock-melting of carbonates.

Pyroxene in the second section is strongly mosaized. Carbonates are widely distributed although crushed zones are relatively rare, suggesting that the zones were not conduits for the entry of CO<sub>2</sub>-rich fluids into the rock. Near the edge of one pyroxene crystal there are numerous (~15) irregularly shaped carbonate grains (10-50 µm in size) and many generally smaller plagioclase glass inclusions; both phases appear to be sealed inside the pyroxene crystal. We infer that carbonate and plagioclase grains that were originally located on a pyroxene grain boundary were shock melted and the melts injected less than a millimeter along fractures.

Many elongated carbonates, typically 5-20 by 50-200 µm, and smaller grains of plagioclase glass, 5-50 µm in size, are aligned along both sealed and open cracks in pyroxene. Like other carbonates they are chemically zoned; some have calcite-rich centers and magnesite-rich ends and one crystal is shaped like a convex lens. Open cracks appear to postdate the formation of carbonate and glass and formed along carbonate-rich regions of some sealed cracks. We infer that these elongated carbonates are the disks and irregularly-shaped thin patches that are observed on broken fragments of ALH84001 [4,6,7].

Comparisons with shock melted troilites and plagioclases in silicates in sections of the Rose City H chondrite suggest that carbonate melts in ALH84001 were injected into fractures during shock decompression [1,2]. The morphologies of troilites in Rose City mimic those of carbonates in ALH84001. In both cases, melts were injected along fractures to form various types of inclusions: long (~1 mm), parallel-sided inclusions, planes of isolated irregularly-shaped inclusions, or sets of plates that appear in thin section as trains of elongated grains. Two kinds of rounded, radially zoned carbonates formed in ALH84001: disks and globules. Disks formed in fractures from squeezed films of melt and are readily visible on broken surfaces. Globules that have been described in some thin sections are surrounded by plagioclase glass, normally appear as broken fragments and occur interstitially between large pyroxenes [5,6,8]. Globules probably formed from carbonate-plagioclase melts that were not homogenized because of the high viscosity of plagioclase melts, and were not injected into fractures. Injected melts typically formed separate inclusions of plagioclase glass and carbonate along fractures.

Models for carbonate formation that invoke either alteration of plagioclase, pyroxene and olivine by fluids [8-10] or deposition at low-temperatures in cracks and pores [4,7] fail to satisfy many petrologic constraints. Alteration models cannot explain how carbonates could form inside plagioclase and why carbonates in pyroxene and plagioclase have similar chemical zoning. Low-temperature deposition models fail to explain the shapes of subhedral, rounded and cusped surfaces of large carbonates in contact with pyroxene, which resemble plagioclase glass boundaries, and the healing of carbonate-bearing cracks in pyroxene. Both types of models fail to account for high concentrations of large carbonate grains up to 50 µm wide in localized regions of pyroxene crystals and carbonate globules in plagioclase glass. Models that do not involve strong shocks fail to explain how carbonate crystals could have experienced the >25-45 GPa shock that melted plagioclase [1,2] without extensive deformation, recrystallization, melting or devolatilization of carbonate [e.g., 11,12]. Carbonates crystallized before glass formed [8,13], and any removal of shock features by recrystallization would have homogenized the micron-scale chemical zoning.

Our model for carbonate formation differs from the high-temperature impact model of Harvey and McSween [9,10] in which carbonates formed by reaction between silicates and a hot CO<sub>2</sub>-rich fluid flowing through brecciated conduits over periods of hours. The cogent criticisms of this model by Valley et al. [7] do not apply to the shock melting model as tiny volumes (~1%) of carbonate melt would have been mobilized during shock decompression and cooled in seconds by large volumes of cool pyroxene.

**References:** [1] Scott E.R.D. et al. (1997) LPS 28, 1271-1272. [2] Scott E.R.D. et al. (1997) *Nature*, in press. [3] Ash R.D. et al. (1996) *Nature* 380, 57-59. [4] McKay D.S. et al. (1996) *Science* 273, 924-930. [5] Mittlefehldt D.W. (1994) *Meteoritics* 29, 214-221. [6] Mittlefehldt D.W. (1996) <http://sn-charon.jsc.nasa.gov/alh84001/sample.htm>. [7] Valley J.W. et al. (1997) *Science* 275, 1633-1638. [8] Treiman A.H. (1995) *Meteoritics* 30, 294-302. [9] Harvey R.P. and McSween H.Y. (1996) *Nature* 382, 49-51. [10] Harvey R.P. and McSween H.Y. LPS 26, 555-556. [11] Lange M.A. and Ahrens T.J. (1986) *EPSL* 77, 409-418. [12] Martinez I. et al. (1995) *JGR* 100, 15,465-15,476. [13] McKay G. A. and Lofgren G.E. (1997) LPS 28, 921-922.